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Endorsement of proprietary products for permanent reinforced fill structures in Hong Kong

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ABSTRACT : Description is given of the Endorsement Certificate System for the prior approval of proprietary products intended for use in permanent reinforced fill structures in Hong Kong. The aspects which are examined in the assessment of submissions from manufacturers and suppliers seeking endorsement of proprietary products are then outlined. Results are presented from a detailed study of stress rupture in HDPE geogrids for establishing long-term design loads under Hong Kong temperature conditions.

1 INTRODUCTION

In the past few years increasing interest has been shown in the use of polymer and steel reinforcements in earth structures in Hong Kong. In 1989, the Geotechnical Engineering Office (the then Geotechnical Control Office) of the Hong Kong Government published the Model Specification for Reinforced Fill Structures (Geospec 2) (GCO, 1989) to provide guidance on design and construction of reinforced fill structures. At the same time, an Endorsement Certificate System was introduced for the prior approval of proprietary products intended to be used in permanent reinforced fill structures in Hong Kong (Pang, 1991).

This paper describes the Endorsement Certificate System and outlines the aspects which are examined in the assessment of submissions from manufacturers and suppliers seeking endorsement of proprietary products.

2 THE ENDORSEMENT CERTIFICATE SYSTEM

The specification clauses and design method given in Geospec 2 have been prepared mainly to cater for materials which have been widely used in Hong Kong, viz steel strips. However, many different proprietary products have been developed for use in reinforced fill structures. Because of their variety, and the complex design features incorporated in many of these products, it is considered impractical to define standard properties and performance parameters which will cover all available products, as well as those which may become available in future. Also, from time to time, new materials will become available for which no established standards exist. Therefore, Geospec 2 adopts an Endorsement Certificate System for the acceptance of proprietary products intended to be used in permanent reinforced fill structures in Hong Kong.

The Endorsement Certificate System is based on 'approval' certificates issued by established national organisations such as the British Board of Agrément (BBA) and the Institute für Bautechnic in Germany. Where a national 'approval' certificate is considered to be partially or fully applicable to Hong Kong conditions, an Endorsement Certificate is issued by the Director of Civil Engineering for use of the product in Hong Kong, specifying any additional or conflicting requirements. Allowable design loads for proprietary reinforcing elements to be used under Hong Kong conditions are also given in the relevant Endorsement Certificates.

The following aspects are considered during the assessment of endorsement submissions :

1. The existence of a national certificate, and the conditions and duration for which it is valid.
2. Durability and specification of materials used in the proprietary products.
3. Steps undertaken by the manufacturer/ supplier to ensure that the products are of adequate quality.

4. Specification of fill for use with the products.

5. Requirements for compliance testing of the products and of the fill during construction.

6. Ease of construction and precautions required during installation and use.

7. Allowable design loads and other relevant design considerations.

The adequacy of the manufacturer's instructions for design, construction and testing in conjunction with Geospec 2 and the national certificate, and any conflicts between these documents, are also examined.

The requirements of Geospec 2 form the basis of checking of endorsement submissions from manufacturers and suppliers. Special tests to prove satisfactory long-term performance of the proprietary products under Hong Kong conditions may be required.

The Endorsement Certificate System confers a level of acceptance on reinforced fill proprietary products. The object of the Endorsement Certificate System is to ensure consistent and satisfactory standards in the provision of such products, to facilitate their specification and to save time for designers, contractors, manufacturers/suppliers and Government by eliminating repetitive checking of project proposals. Some aspects of assessment of polymer and steel reinforcements are discussed below.

3 ASSESSMENT OF POLYMER REINFORCEMENTS

3.1 Use of Polymer Reinforcements in Hong Kong

The first Endorsement Certificate was issued in Decemeber 1990. This covers two geogrids (Tensar SR80 & SR110) from a UK manufacturer, both of which are produced by drawing a pierced roll of high density polyethylene (HDPE) into highly oriented ribs between 'nodes' of lightly drawn material. Up to the present, a total of six reinforced fill slopes incorporating these geogrids have been constructed. In the assessment of the geogrids for endorsement purposes, a great deal of attention has been given to the subject of stress rupture.

3.2 Stress Rupture and Temperature Considerations

The polymers form a special class of proprietary reinforcing materials which can exhibit stress rupture behaviour under sustained loading. For these materials, temperature has been identified as an important consideration in the derivation of long-term stress rupture loads. This is because the in-service ground temperature in Hong Kong can be fairly high : a maximum temperature in the range of 30°C to 35°C is considered likely at the soil/concrete interface of retaining walls built with concrete facing panels (Howells & Pang, 1989). Therefore, stress rupture testing at elevated temperatures is necessary. Apart from the need to ensure that tertiary creep (which leads to stress rupture) will not occur throughout the design life of the earth structure, long-term creep strains must also be taken into account in design as these may give rise to serviceability problems.

3.3 Study of Stress Rupture in HDPE Geogrids

There is a concern regarding the possibility of low-strain fracture in HDPE geogrids. One reason for this is the behaviour of unoriented HDPE gas pipes in which there is a transition from high-strain ductile to low-strain brittle behaviour at long durations. The consequences of sudden failure occurring in a densely populated area such as Hong Kong could be so catastrophic that it is essential that any such possibility must be excluded.

ERA Technology Ltd UK was commissioned by the Geotechnical Control Office in 1989 to carry out an in-depth literature review of the phenomenon of stress rupture in HDPE grids. The study was completed in 1991 (Small & Greenwood, 1991).

Stress rupture data were provided by the manufacturer for the study, which included results of creep tests on different Tensar geogrids at 10°C, 20°C and 40°C, some of which ended in rupture. The 40°C tests were specifically carried out by the manufacturer to provide data in support of its endorsement submission. These tests were independently verified by ERA. Some tests were of very long durations and, although terminated before rupture, provided a minimum value to the rupture lifetime.

3.4 Extrapolation of Time to 10% Strain and Time to Rupture

Since rupture was always found to occur at strains exceeding 10% and frequently 15%, the manufacturer, with the aim of

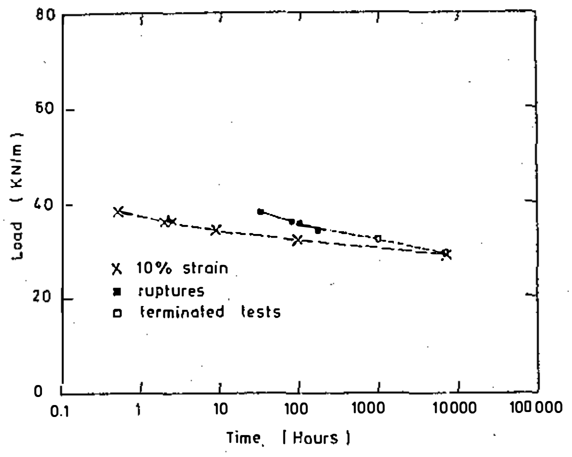

Figure 1 Stress rupture data for SR80 at 40°C

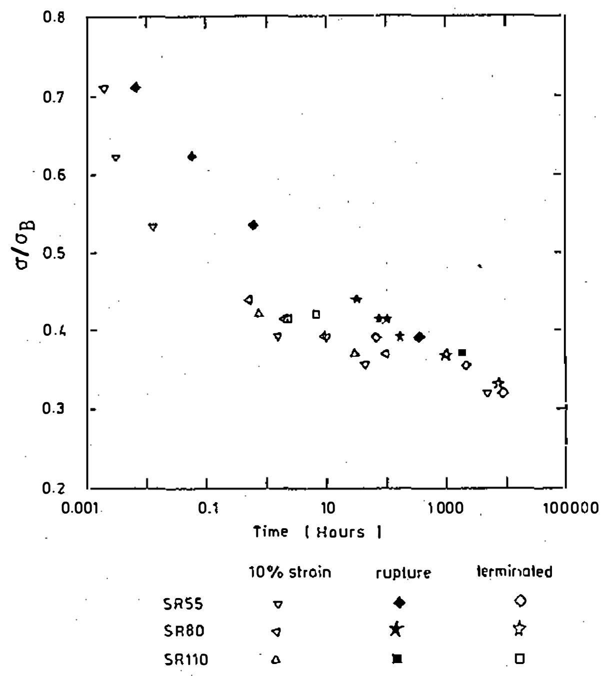

Figure 2 Normalised data for SR55, SR80 and SR110 at 40°C

protecting its equipment, had kept the creep test measurements going beyond 10% strain, but took the instruments off the test specimens at strains beyond 10% when rupture was imminent or at the end of a test programme. Consequently, there is less data on time to rupture than on time to 10% strain. Instead of providing extrapolated times to rupture, the times to 10% strain were extrapolated by the manufacturer to provide a design limit based on a strain of 10% (referred to as the performance limit strain) at 120 years.

The difference between extrapolation of times to 10% strain and times to rupture is illustrated by the results of Tensar SR80 at 40°C, as shown in Figure 1. It appears that the extrapolated rupture curve may cross the extrapolated times to 10% strain, i.e. that at long time durations rupture may occur at strains below 10%. It is therefore important to base design loads upon rupture data, using the extrapolated 10% strain data as a reference only.

3.5 Analysis and Curve Fitting

In ERA's analysis, the test loads (σ) for the stress rupture tests were normalised, i.e. these were expressed as a fraction of the corresponding mean batch strength (σ_B) provided by the manufacturer. The results from Tensar SR55, SR80 and SR110, which are made from the same material with an identical method of manufacture, were then superimposed. The purpose of this is to include more data on a single diagram, thus giving a more reliable extrapolation. The superimposed points for the 40°C data are shown in Figure 2 to illustrate the result of normalisation. Curve fitting was then carried out. Various relations such as linear and parabolic functions were considered based upon the calculated goodness of fit (lowest root mean square of residual errors). A double logarithmic relation was selected :

$$\sigma/\sigma_B = A_o + A_1 \log(\log 10^x t) \quad (1)$$

where A_o, A_1 = coefficients
t = time in hours
x = 1, 2 or 3 to eliminate decimal values of t

Time-temperature superposition (Andrawes et al, 1986) was then applied by shifting the curves for 20°C and 40°C along the time axis to superimpose on that for 10°C. A new curve was fitted to include all the superimposed points. This was then shifted to the design temperature. The direction of shift is such that a rise in temperature corresponds to more rapid creep. The resultant stress rupture curve for 35°C is shown in Figure 3.

The rule for tests terminated without rupture, known as 'run-outs', was as follows. Initially, they were excluded and a curve was calculated for ruptures alone. If when plotted any 'run-outs' appeared to the right of the curve, they would have been introduced into the calculation and a new curve calculated; if they appeared to the left they were excluded. In the event no 'run-outs' were used in the calculation.

The extrapolated rupture loads at 10^6 hours at various temperatures are given in Table 1.

It should be noted that as σ approaches σ_B, the theoretical stress rupture curve approaches the vertical axis asymptotically. Therefore, the mathematical model used, although suitable for extrapolation to small loads and long times, is not representative at the high loads and short times.

3.6 Evidence of 'Brittle' Failure

As mentioned earlier, in unoriented pipe grade HDPE two rupture mechanisms have been observed. At high loads and short times rupture is ductile and the stress rupture graph extrapolates to long rupture lifetimes. At lower loads and longer time intervals, however, there is a transition to more brittle failure (strain to failure between 5% and 35%), leading to reduction in extrapolated lifetime. This transition or 'knee' exists for any grade of unoriented material. From the data available, there appears to be only one mode of rupture in the oriented Tensar geogrids: it occurs in the ribs at strains similar to the 'brittle' failure of unoriented polyethylene, but it is not possible to state that the two processes are the same. On the available evidence, Small & Greenwood (1991) have proposed that there is no 'knee' in the stress rupture graph of Tensar geogrids, although with the limited evidence available a partial safety factor is recommended.

3.7 Quality Assurance of HDPE Geogrids

The approach adopted by the manufacturer of the geogrids to ensure product quality is that the manufacture of the products is covered by a national (BSI) quality assurance scheme, with quality procedures laid down to a national standard (BS5750:Part2:1987) and verification carried out by an independent organisation (BSI QUASAR). Geogrids supplied to Hong Kong are labelled to identify the product type and the manufacturing code, hence traceability is ensured. Each roll of geogrids has an identification mark to confirm that the national (BBA) certificate is current. A copy of the manufacturer's test certificate will accompany each order through the Hong Kong distributor. For the quality assurance provided, no additional compliance testing has been specified in the Endorsement Certificate. The burden of checking compliance in a contract rests with the Engineer, who may confirm with the local distributor the source of the materials delivered to site. The Engineer may also follow the advice given in Geospec 2 to take samples of the geogrids during placement into the works and send them to the manufacturer or an independent laboratory for verification testing.

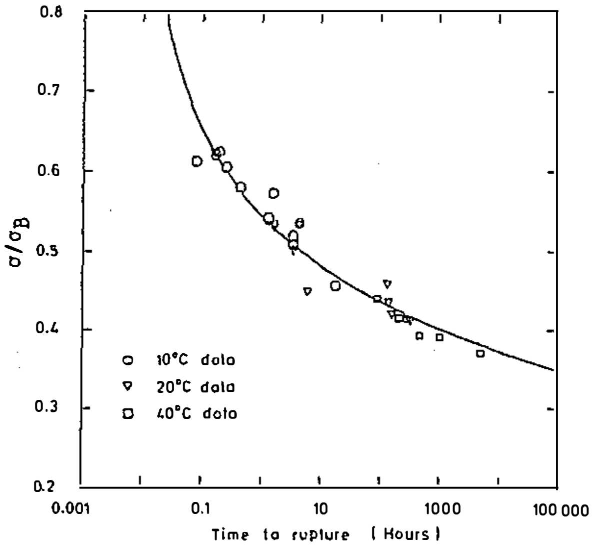

Figure 3 Time-temperature superposition of SR55, SR80 and SR110 rupture data at 35°C

Table 1. Extrapolated rupture loads for Tensar SR55, SR80 and SR110

Temperature	Extrapolated Rupture Loads in kN/m		
	SR55	SR80	SR110
20°C	17.8	25.8	35.6
25°C	17.2	25.0	34.4
30°C	16.6	24.2	33.2
35°C	16.1	23.4	32.2
40°C	15.6	22.7	31.2

4. ASSESSMENT OF PROPRIETARY STEEL PRODUCTS

4.1 Use of Proprietary Steel Products in Hong Kong

The first permanent reinforced fill structure in Hong Kong was completed in early 1980 using ribbed steel strips as reinforcement. A total of thirteen steel reinforced fill structures (all retaining walls) have been constructed since then. At the time of writing, the assessment of submissions from two suppliers, covering three types of ribbed steel strips as well as six types of welded steel meshes, is in progress. The main focus in the assessment of proprietary steel reinforcements is the quality assurance aspects of the products, which will be discussed below.

4.2 Quality Assurance of Proprietary Steel Products

While the approach described in Section 3.7 is a requirement for products made of new materials, it is not considered appropriate for products made of conventional materials. For structural steelwork and steel reinforcing bars used in structural concrete in Hong Kong, local practice is to specify that the steel shall meet the relevant BS. In a contract, the steel may come from a number of sources, and the Engineer will require the Contractor to submit a mill certificate (containing information on chemical composition and mechanical property data) to prove compliance. Depending on the circumstances, the Engineer may also select random samples for independent testing. This approach is however not rigorous enough for the purpose of endorsement. In the assessment of proprietary steel products, the approach outlined below has been adopted.

First of all, the steel and the galvanizing are required to be specified either to meet the relevant BS's or other national standards which are equivalent to the BS's. The supplier has to nominate the alternative sources of supply and galvanizers to be used for each product. Copies of typical mill certificates from each manufacturer and test certificates from each galvanizer have to be provided.

Where the manufacturers of the steel products and the galvanizers used are covered by national quality assurance (Q.A.) schemes, evidence relating to such schemes (e.g. certificates from the approval body) is examined. In such cases, the procedures adopted for geogrids regarding identification of the products and confirmation of validity of the Q.A. schemes on delivery to construction sites in Hong Kong are applicable. No additional compliance testing would need to be specified in a contract, but the Engineer may still take selected samples of the product during placement into the works for independent verification testing.

For products which are not covered by an acceptable Q.A. scheme, the supplier is required to demonstrate that adequate measures have been taken to ensure acceptable quality of the products. In this regard, the following information is examined :

1. Specifications used by the supplier in the procurement of the products and the galvanized coating.
2. Conditions specified by the supplier which are related to quality control (Q.C.) procedures to be used by the nominated manufacturers and galvanizers, including the type and frequency of Q.C. tests, the testing standards, acceptance/rejection criteria, the form of mill and test certificates to be issued and identification codes for manufactured batches given on such certificates.

For the nominated manufacturers and galvanizers, third party Q.A. by a national body is preferred. However, where this is not provided, then information related to in-house quality assurance is required to be examined. In such cases, compliance testing will need to be specified, and the supplier will have to engage an independent accredited testing agency to carry out such tests. The type of tests to be carried out, the testing standards and the acceptance/rejection criteria would depend on the functional requirements of the products, all to be agreed with the supplier. The frequency of testing will be determined with due account taken of the Q.C. procedures of the nominated manufacturers and galvanizers.

In both of the above cases, information on shipment, storage, delivery and site identification of the products is also examined.

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